# APPENDIX C
# SLUG TEST ANALYSES

Slug tests are a means by which a single well can be utilized to estimate the horizontal hydraulic conductivity of saturated subsurface soil. Slug tests are generally used as a low cost substitute for more expensive aquifer tests. Although slug tests are widely used and generally accepted, it should be remembered that slug tests yield only local values of horizontal hydraulic conductivity (within a close proximity to the well). Values obtained from slug tests should therefore be used with caution when extrapolating regional values for a heterogeneous aquifer system.

## C.1 SLUG TEST DATA COLLECTION

A slug test is a rate-of-rise test where the hydraulic conductivity is determined from the rate of rise of the water level in a well after this level was abruptly lowered by the sudden removal of a certain volume of water from the well. There are many different methods for abruptly removing a certain volume of water from a well or achieving the same effect. At the Tennessee Products Site, a 5-foot long, 1.5-inch diameter, PVC slug was first inserted into the well. The water level was allowed to equilibrate and the slug was then quickly removed, thus effecting the removal of a volume of water equal to the volume of the slug. To record the rate of rise of the water level, a water level transducer and data recorder were used. The data logger records the recovery of the well by recording the head of water, as measured by the transducer, at preset increments of time until the water level in the well has recovered to or near its static water level. Short time increments are used at the beginning of the test when recovery is quick, and longer time increments of time are used toward the end of the test when recovery is slower.

## C.2 ANALYSIS OF SLUG TEST DATA

Once the slug test has been performed and the data collected, there are several different methods which can be used to estimate the value of hydraulic conductivity. The appropriate method depends on the characteristics of the aquifer in which the slug test was performed. Some of the characteristics which should be examined are whether the aquifer is confined, semi-confined, or unconfined, and whether the well tested is fully or partially penetrating the aquifer.  At the Tennessee Products Site, the slug tests were performed in an unconfined aquifer with some wells fully penetrating the aquifer and some wells partially penetrating the aquifer.  This combination of aquifer and well characteristics lends itself well to the Bouwer and Rice method of slug test data analysis.  This method is described below.

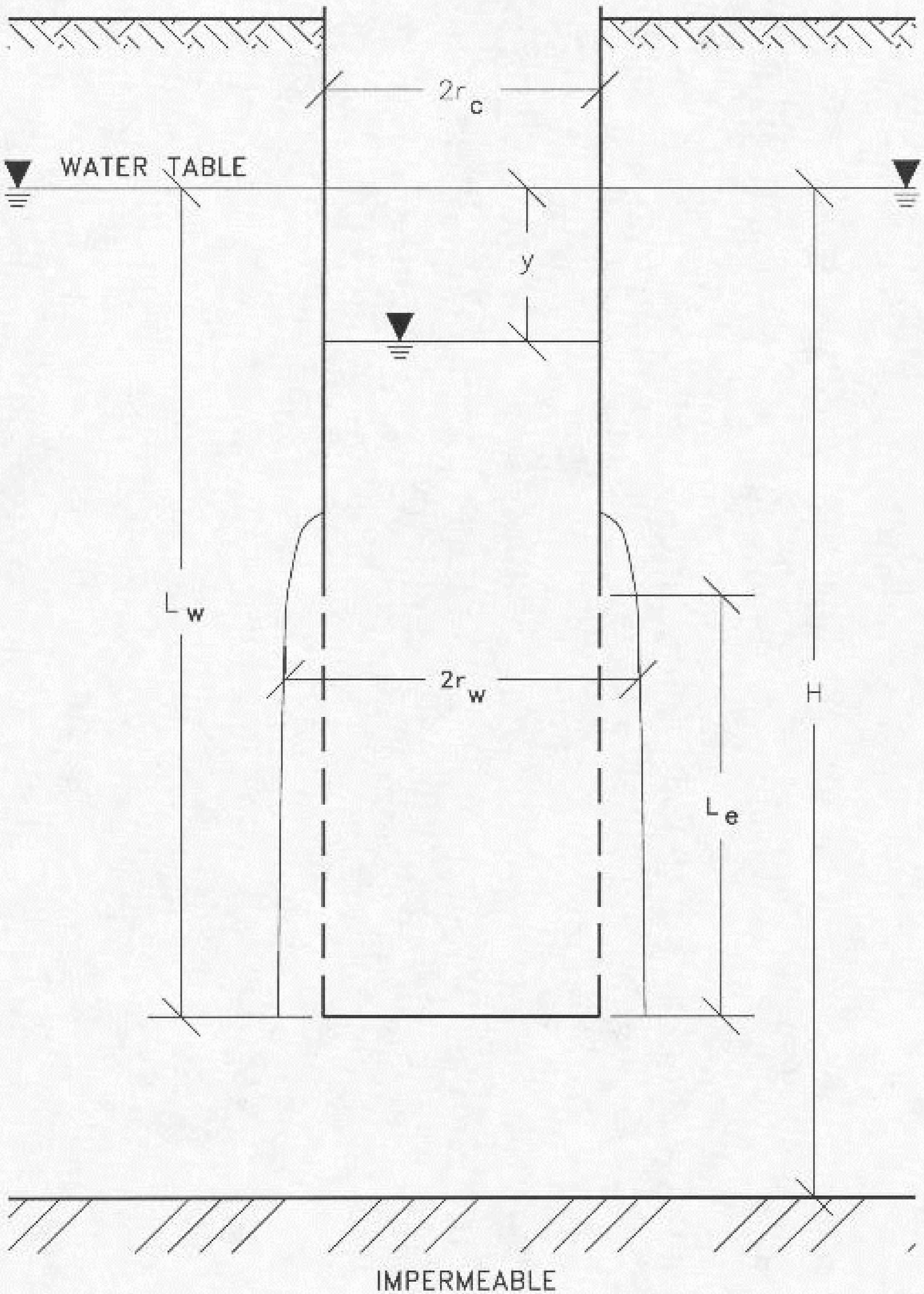
H. Bouwer and R.C. Rice (1978) introduced a method which can be used to analyze slug test data collected from fully or partially penetrating wells in unconfined aquifers.  The method can also be used on semi-confined aquifers that receive most of their water from leakage from the upper confining bed.  The solution is based on the Theim equation and assumes negligible drawdown of the water table around the well and no flow above the water table.  The solution is described by the following equation:

$$K = \frac{r_c^2 \ln(R_e/r_w) \ln(y_o/y_t)}{2 L_e t} \qquad \text{(Eq. 1)}$$

where:

| | | |
|---|---|---|
| $K$ | = | hydraulic conductivity |
| $r_c$ | = | radius of the well section where the water level is rising |
| $R_e$ | = | effective radial distance over which the head difference y is dissipated |
| $r_w$ | = | radial distance between well center and undisturbed aquifer ($r_c$ plus thickness of gravel envelope or developed zone outside casing) |
| $L_e$ | = | height of perforated, screened, uncased, or otherwise open section of well through which ground water enters |
| $y_o$ | = | y at time zero |
| $y_t$ | = | y at time t |
| $t$ | = | time since $y_o$ |

**Figure C-1** shows a schematic monitor well depicting the parameters used in equation (1) above.




## SLUG TEST ANALYSIS GEOMETRY AND SYMBOLS

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Tennessee Products Site
Chattanooga, Tennessee

FIGURE No. C-1

SLUG TEST/29.III.96/1=1

NOTE: If the water level is rising in the screened part of the well during the slug test instead of in its unscreened part, allowance should be made for the fact that the hydraulic conductivity of the zone around the well (gravel/sand pack) may be much higher than that of the aquifer. The value of $r_c$ in equation (1) should be replaced with $r_{eq}$ which is calculated as:

$$r_{eq} = [r_c^2 + n(r_w^2 - r_c^2)]^{0.5} \qquad \text{(Eq. 2)}$$

where:

$n$ = porosity of the gravel/sand pack around well

To determine the values of $\ln(R_e/r_w)$ in equation (1), one of two equations should be used depending on whether the well is fully or partially penetrating. If the well is partially penetrating, the equation used is:

$$\ln(R_e/r_w) = \frac{1}{\dfrac{1.1}{\ln(L_w/r_w)} + \dfrac{A + B\ln[(H-L_w)/r_w]}{(L_e/r_w)}} \qquad \text{(Eq. 3)}$$

where:

$H$ = saturated thickness
$L_w$ = depth from water table to bottom of open section in the well
$A,B$ = type curve constants related to $L_e/r_w$ (see Bouwer, 1978)

If the well is fully penetrating, the equation used is:

$$\ln(R_e/r_w) = \frac{1}{\dfrac{1.1}{\ln(L_w/r_w)} + \dfrac{C}{(L_e/r_w)}} \qquad \text{(Eq. 4)}$$

where:

$C$ = type curve constant related to $L_e/r_w$ (see Bouwer, 1978)

To perform the slug test analysis, a graph of the slug test data is made by plotting the head difference (y) logarithmically on the Y-axis versus time (t) on the X-axis. The section of the graph which best approximates a straight line slope is used to determine $y_o$ , $y_t$ , and t. Once the values for $y_o$ , $y_t$ , t, and $\ln(R_e/r_w)$ are obtained, they are used in equation (1) to calculate the hydraulic conductivity (K).

## C.3 TENNESSEE PRODUCTS SITE SLUG TEST DATA AND RESULTS

Slug tests were performed at 23 of the 24 new monitor well locations at the Tennessee Product Site. A slug test was not performed on monitor well MW-03-IN because data from well development indicated that the well would not recover within 24 hours. Equation (3) was used in the analyses of the partially penetrating wells and Equation (4) was used in the analyses of fully penetrating wells. Equation (2) was used in 12 of the shallow well slug test analyses since the static water level was within the gravel/sand pack around these wells. The slug test analysis data and results for the shallow monitor wells are presented in **Table C-1**. The slug test analysis data and results for the intermediate (fractured bedrock) monitor wells are presented in **Table C-2**. The slug test recovery graphs for each of the 23 monitor wells are presented in the figures following Table C-2. The values of hydraulic conductivity calculated for the shallow wells at the Tennessee Products Site are considered to be within the range expected for silt and silty sand aquifers. The hydraulic conductivity values calculated for the intermediate wells are within the range expected for fractured rocks.

## REFERENCE

Bouwer, H., 1978. *Groundwater Hydrology*, McGraw-Hill Book Company.